

Understanding and Improving Pinning in Coated Conductors

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We use the field, angular and temperature dependences of J_c to identify pinning mechanisms and regimes

Last year we explored the behavior of PLD films on single crystal STO substrates and on IBAD MgO templates, at ~ 75 K.

due to improved texture, our PLD films on IBAD MgO already showed J_c 's equivalent to those on single crystal substrates, so J_c was determined by bulk vortex pinning, and we could use transport measurements to explore it.

The plans for FY 2004 were:

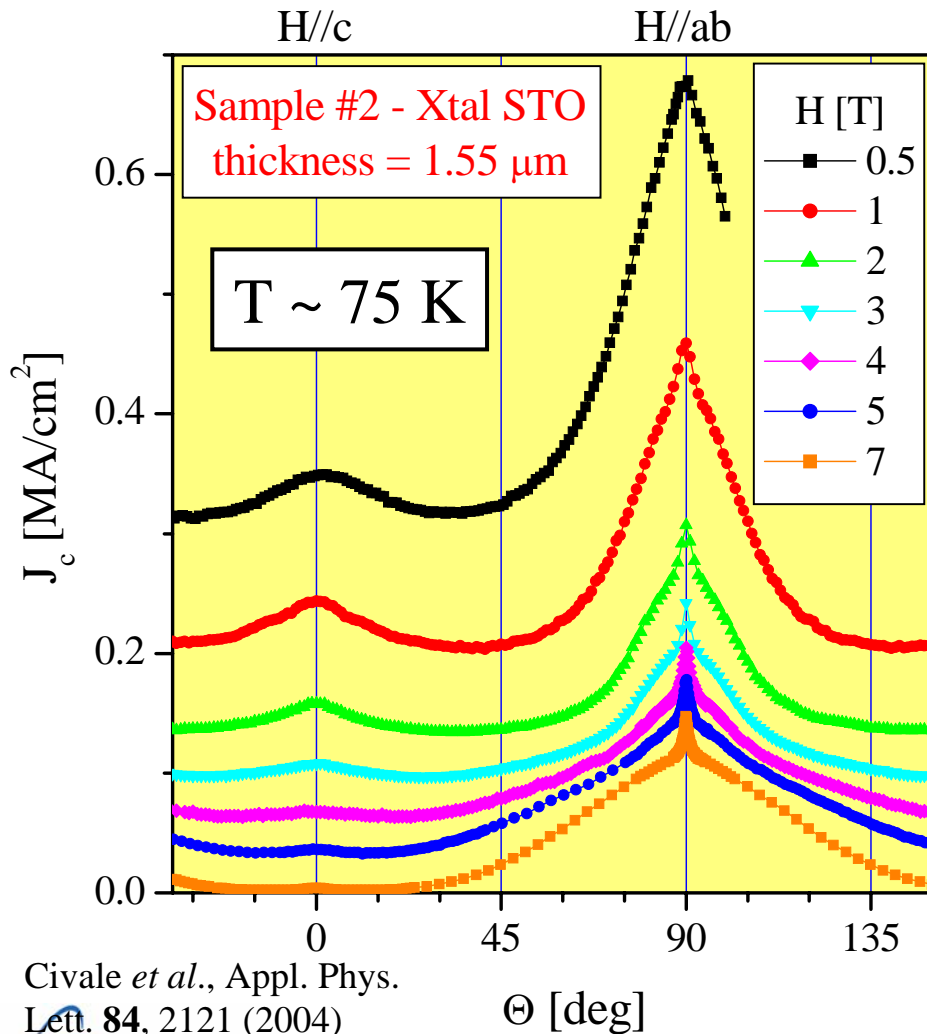
- To extend transport measurements and analysis to lower temperatures.
- To extend the study to films thinner than $1\ \mu\text{m}$.
- To explore the angular dependence of J_c in CC with different architectures.
- To perform J_c measurements with current flowing in different directions in the plane.
- To grow HTS films with rare earth substitutions.
- To introduce columnar defects at different angles.

We use the field, angular and temperature dependences of J_c to identify pinning mechanisms and regimes

Outline:

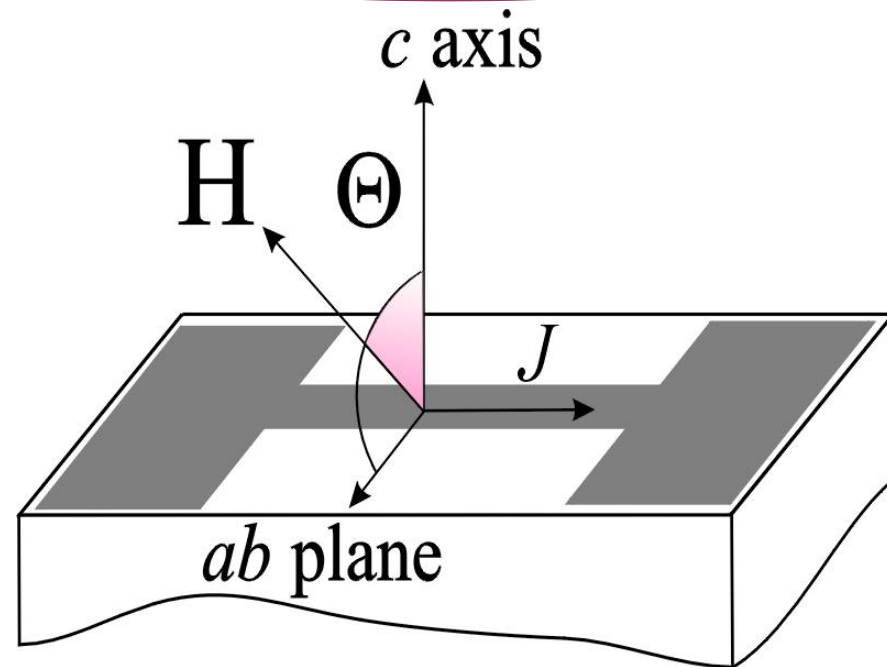
1. Temperature, field and angular dependence of vortex pinning in PLD films
2. Improving pinning
3. Extension of the study to CC grown by different methods
4. Scoring criteria

Field and angular dependence of J_c in PLD films at $T=75\text{K}$.



Civale *et al.*, Appl. Phys.
Lett. **84**, 2121 (2004)

Last year's results

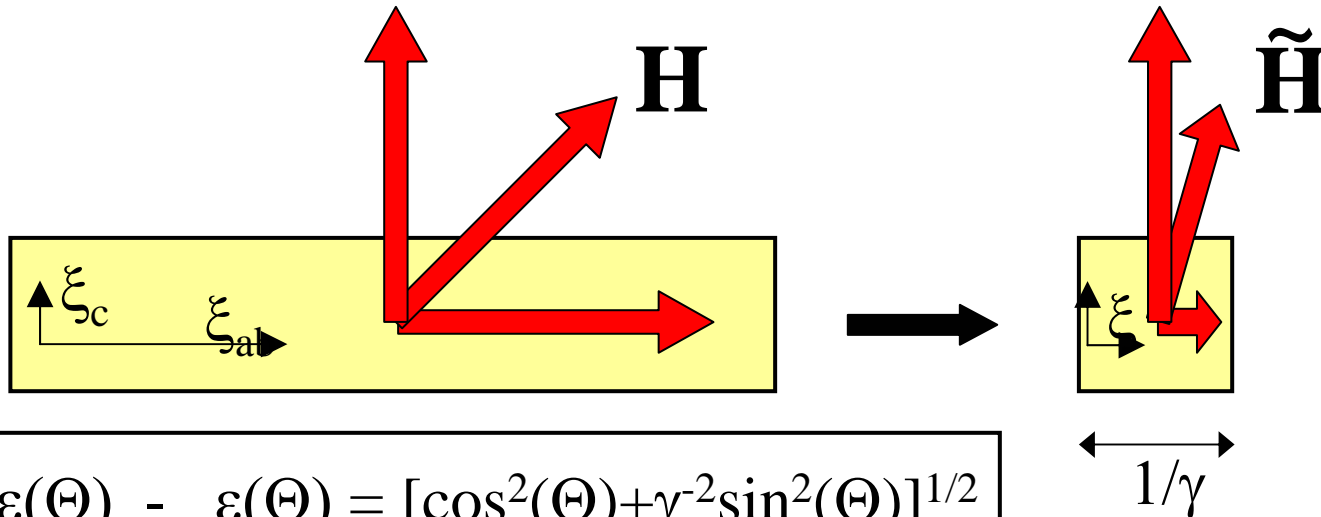


$H \perp J$ always
(maximum Lorentz force)

We developed a scaling method based on YBCO anisotropy to separate random and correlated pinning contributions to J_c

1) Transformation of the magnetic field \mathbf{H}

Blatter et al, Phys. Rev. Lett. 68, 875 (1992)

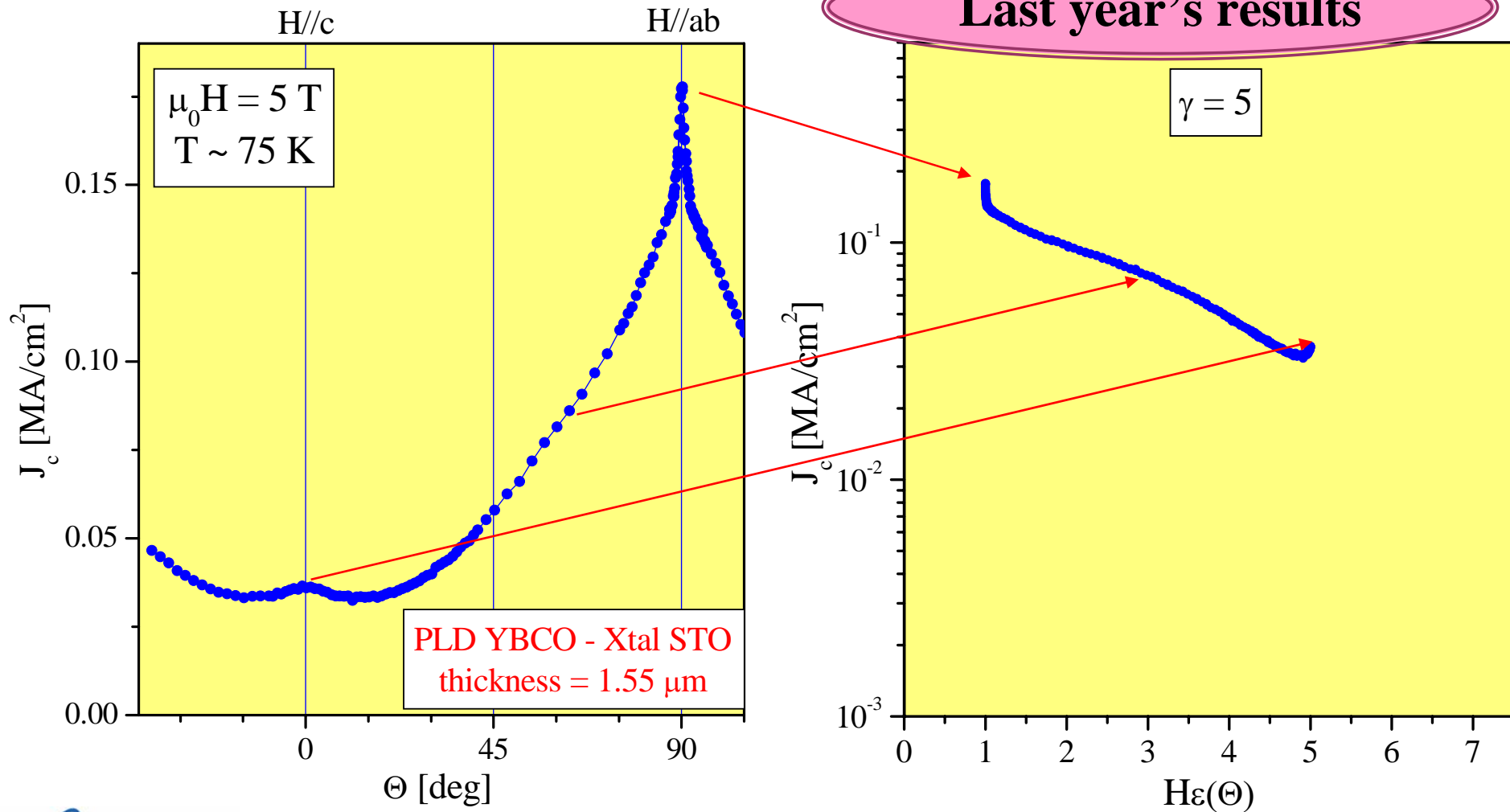


$$\tilde{\mathbf{H}} = \mathbf{H}\varepsilon(\Theta) - \varepsilon(\Theta) = [\cos^2(\Theta) + \gamma^{-2}\sin^2(\Theta)]^{1/2}$$

$\gamma = \text{anisotropy} (\sim 5 \text{ to } 7 \text{ for YBCO})$

2) If pinning is only due to random point defects,
then $J_c(\mathbf{H}, \Theta)$ depends on a single variable: $J_c = J_c[\mathbf{H}\varepsilon(\Theta)]$

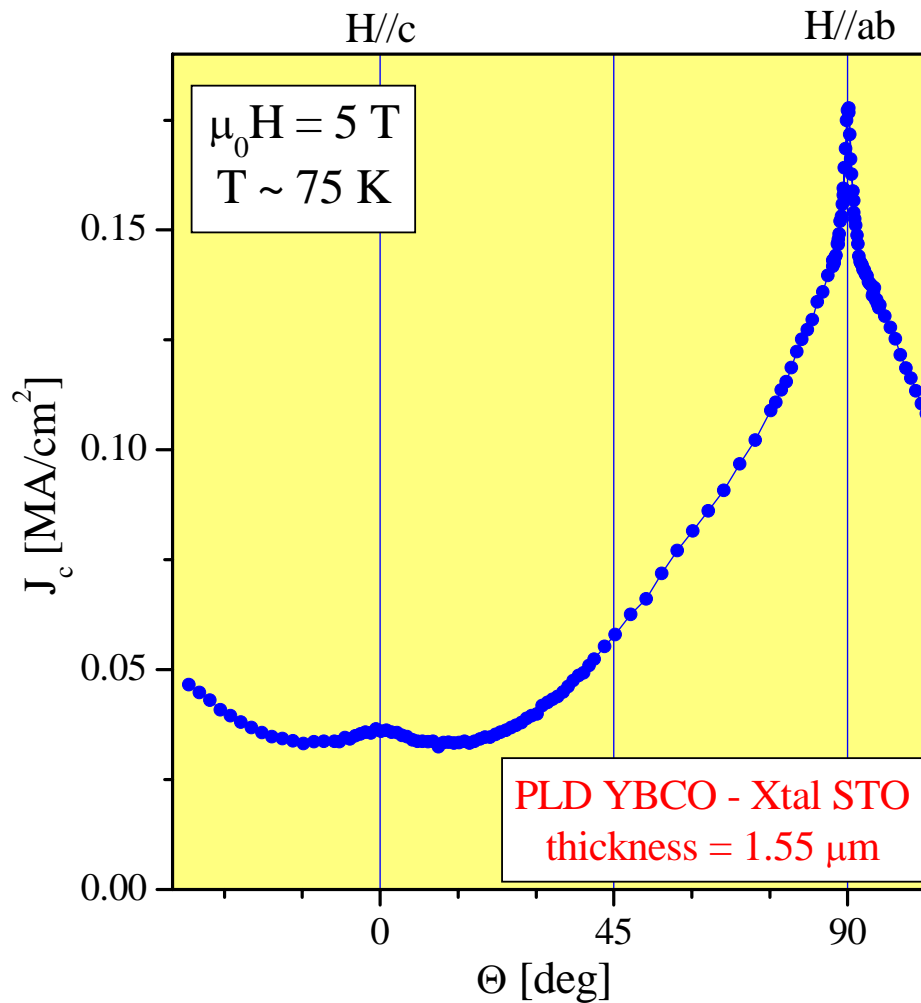
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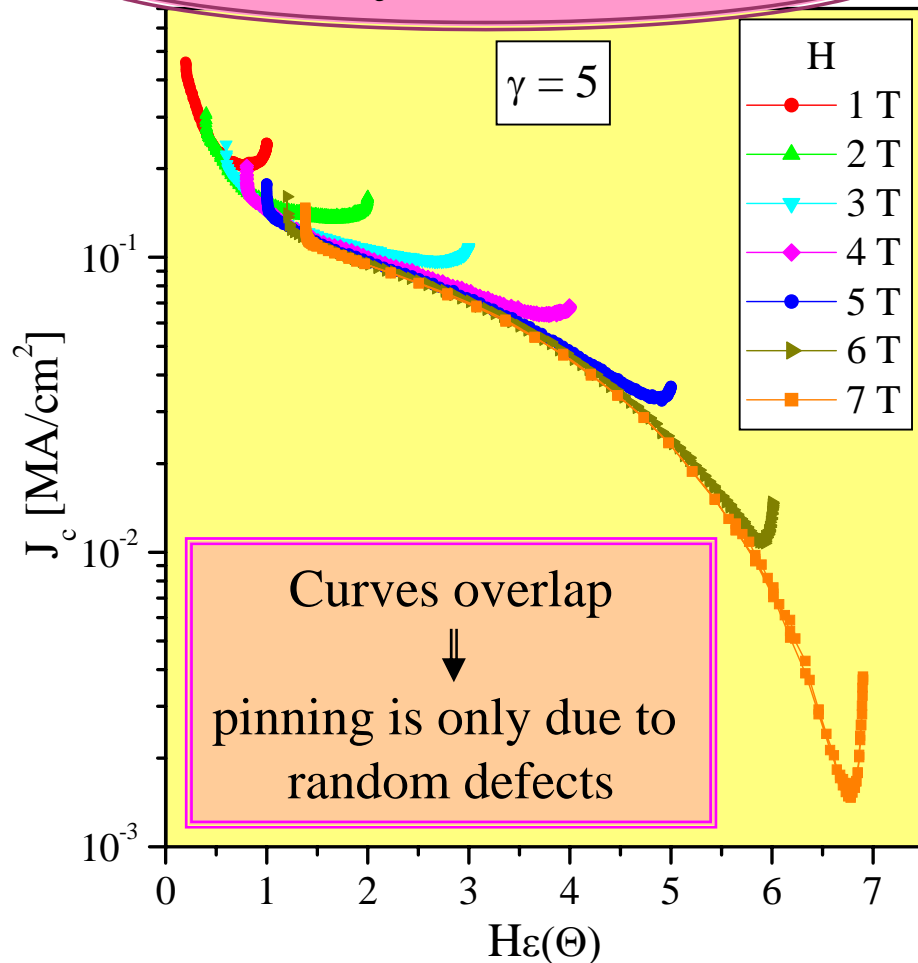
Last year's results

L.C. *et al.*, J. Low Temp. Phys. **135**, 87 (2004).

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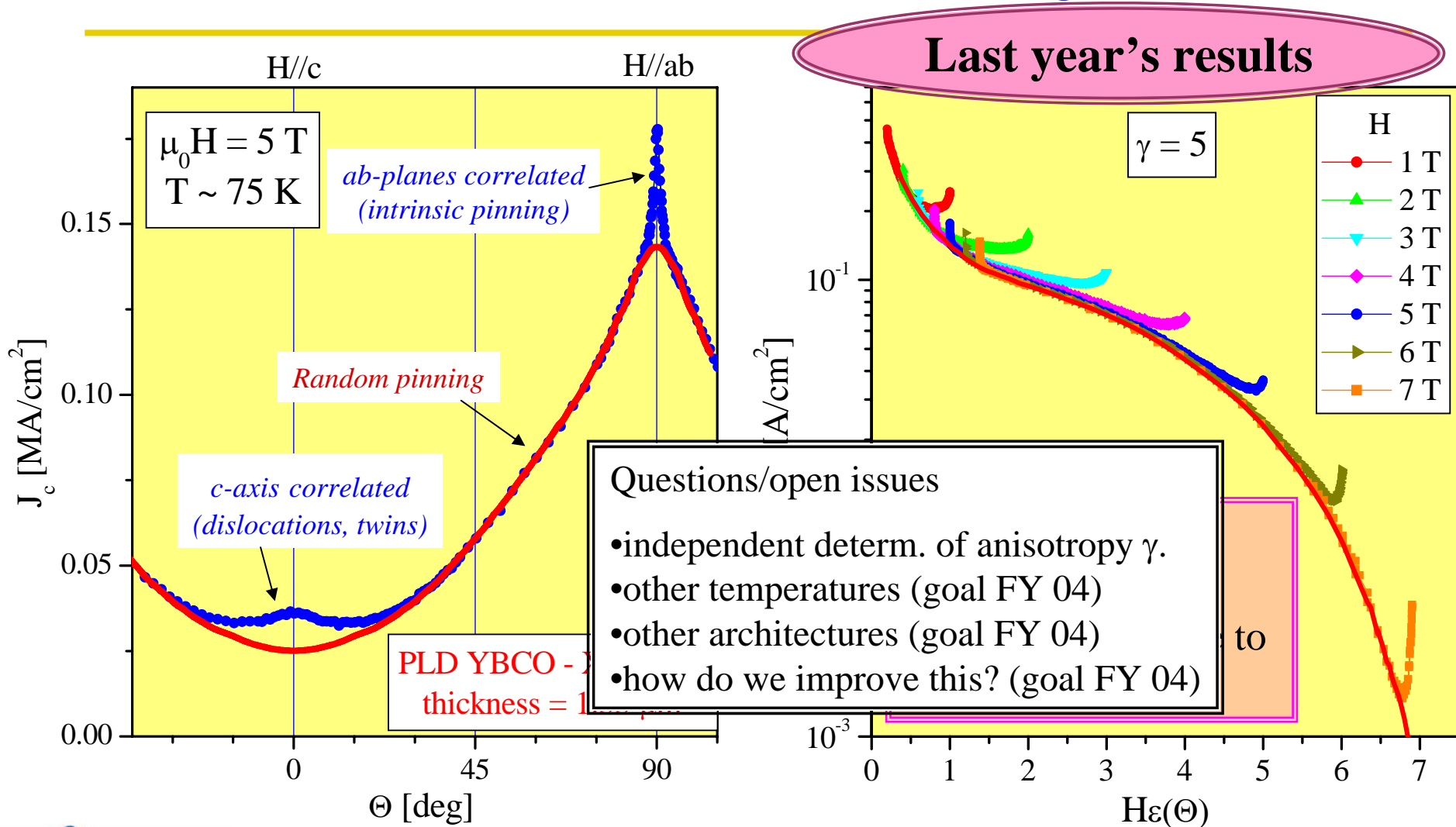


Last year's results



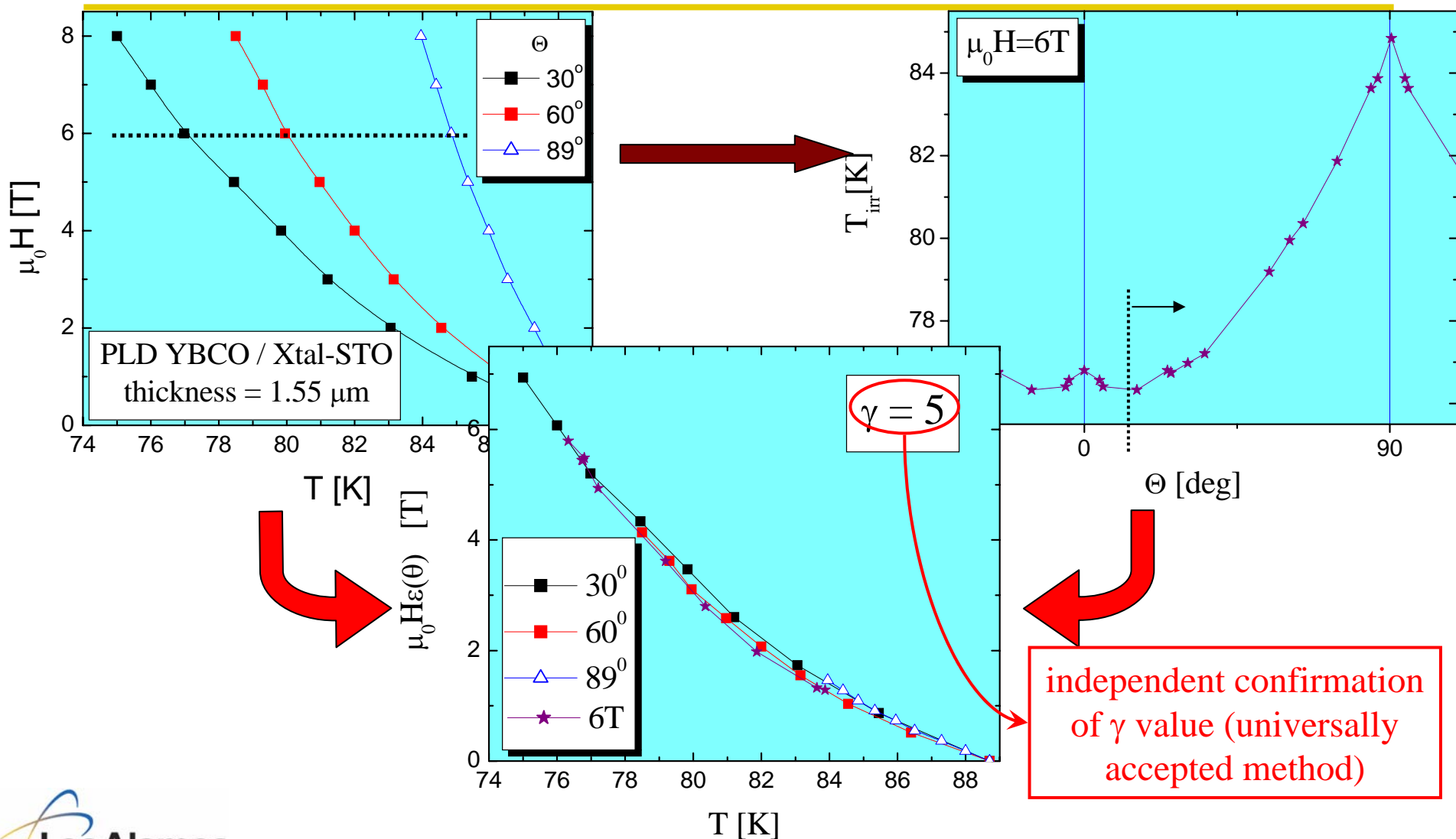
L.C. *et al.*, J. Low Temp. Phys. **135**, 87 (2004).

The angular dependence of J_c arises from a combination of factors and exhibits various regimes

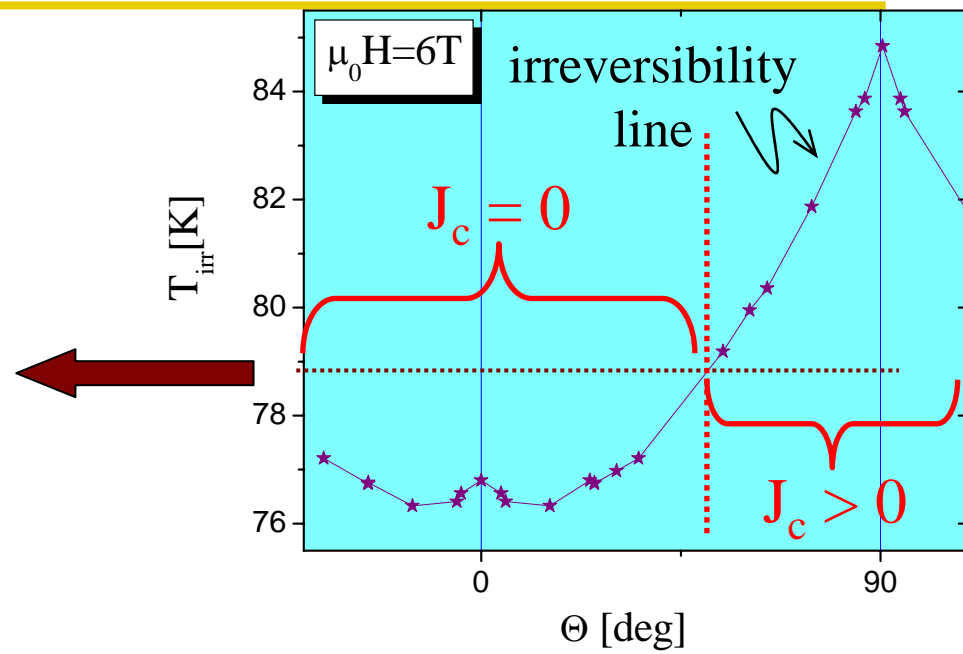
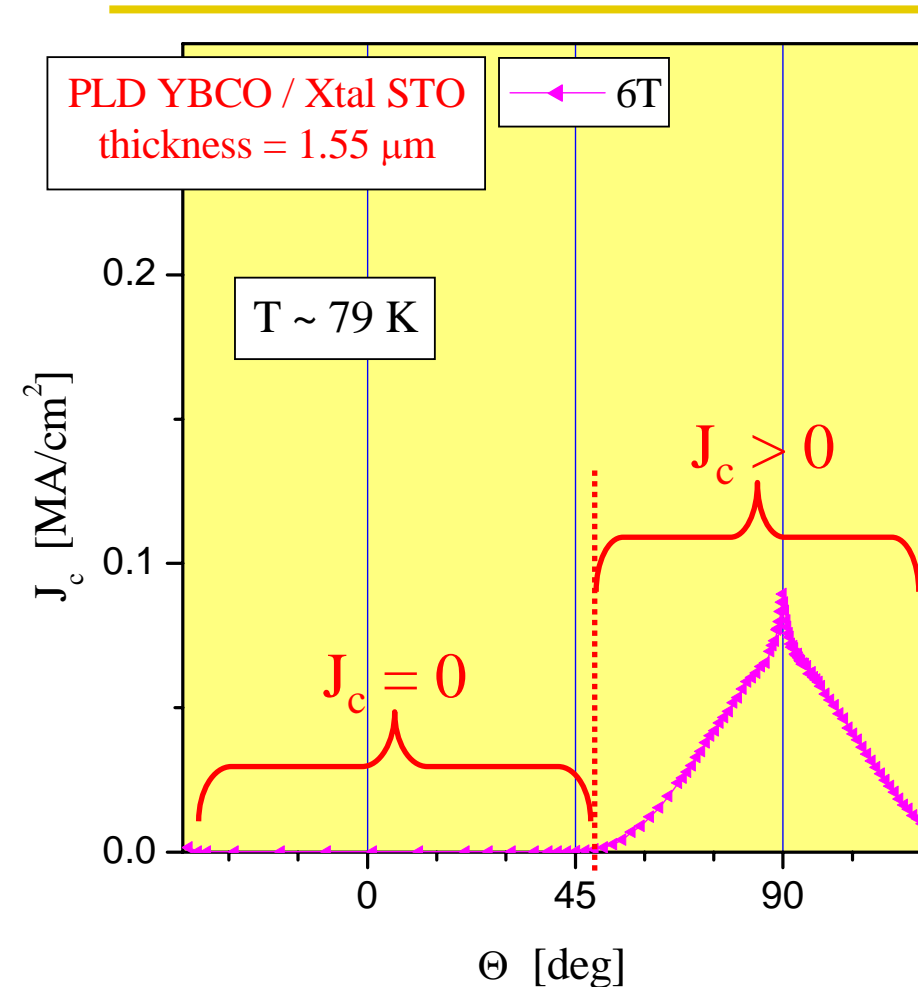


L.C. *et al.*, J. Low Temp. Phys. **135**, 87 (2004).

Angular dependence of the irreversibility line validates our previous analysis based on the electronic mass anisotropy

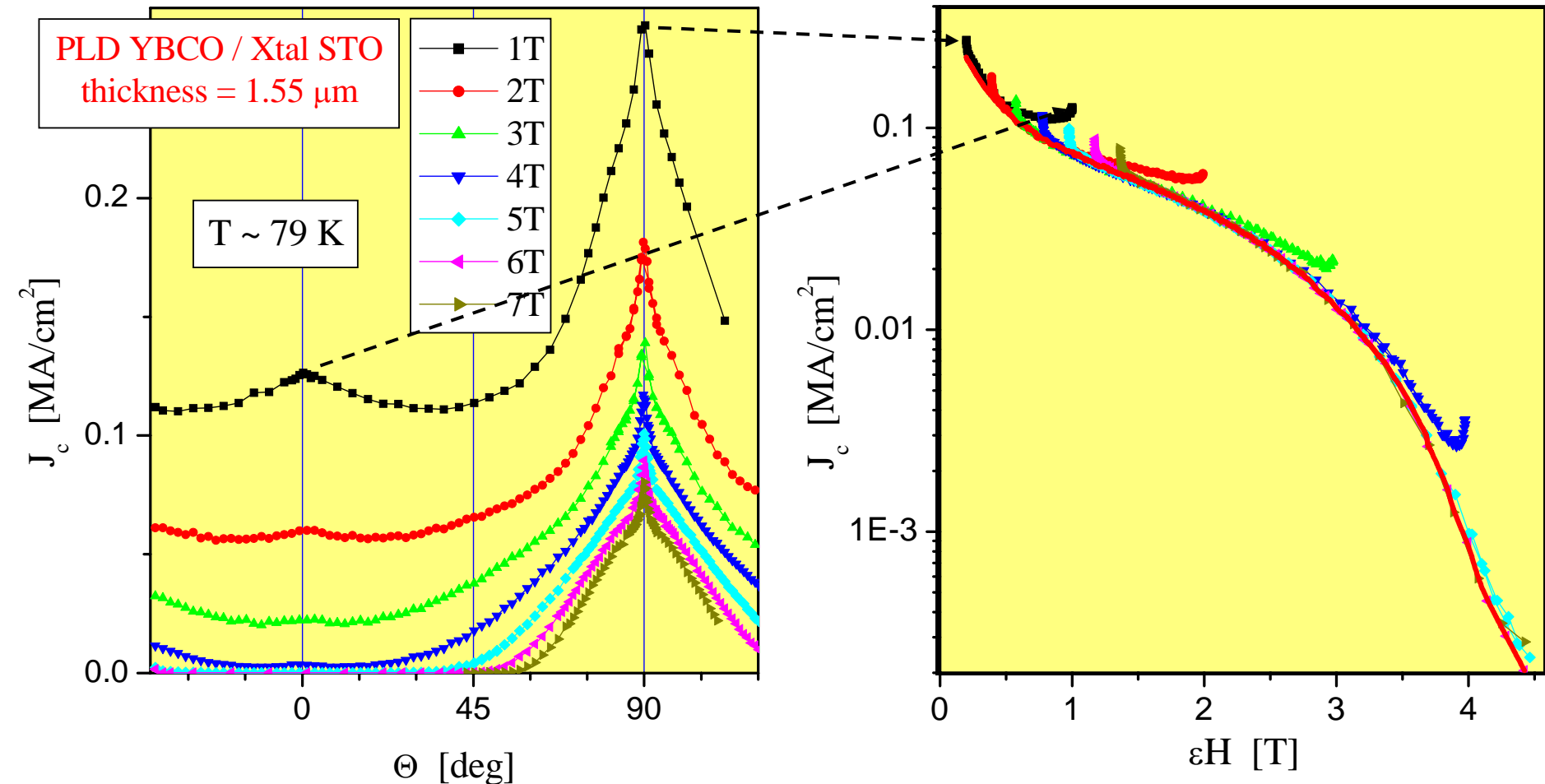


Measurements of I-V curves at 79 K: onset of J_c

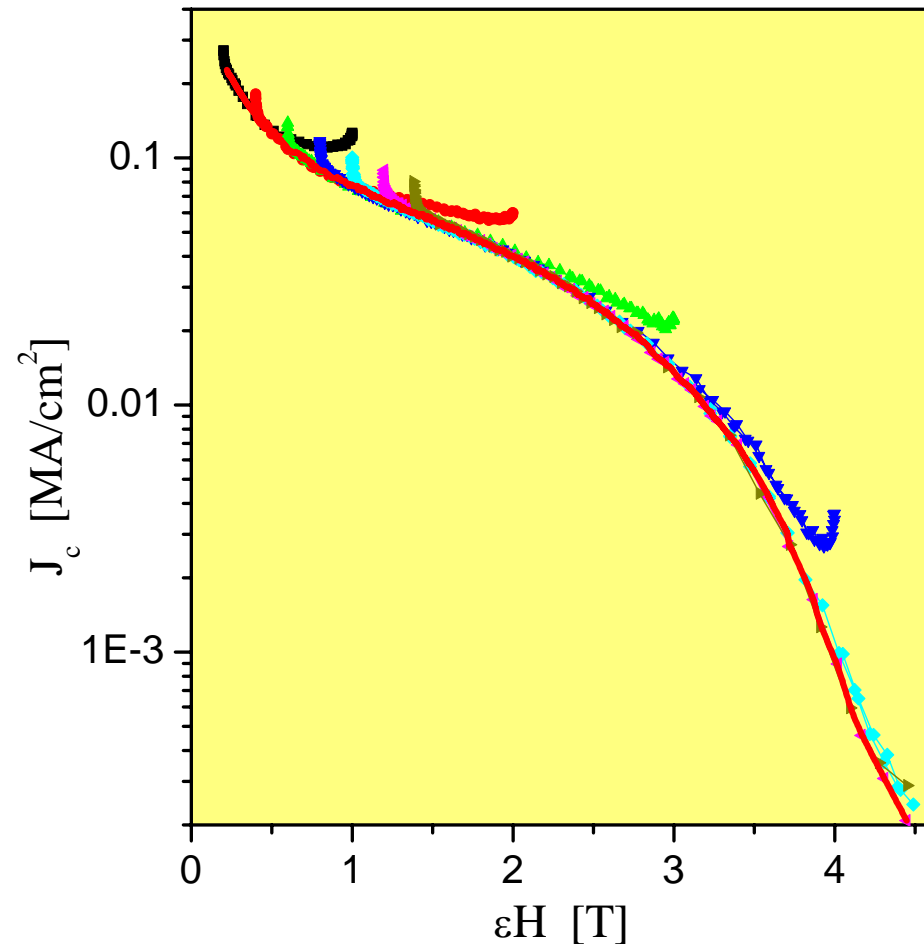
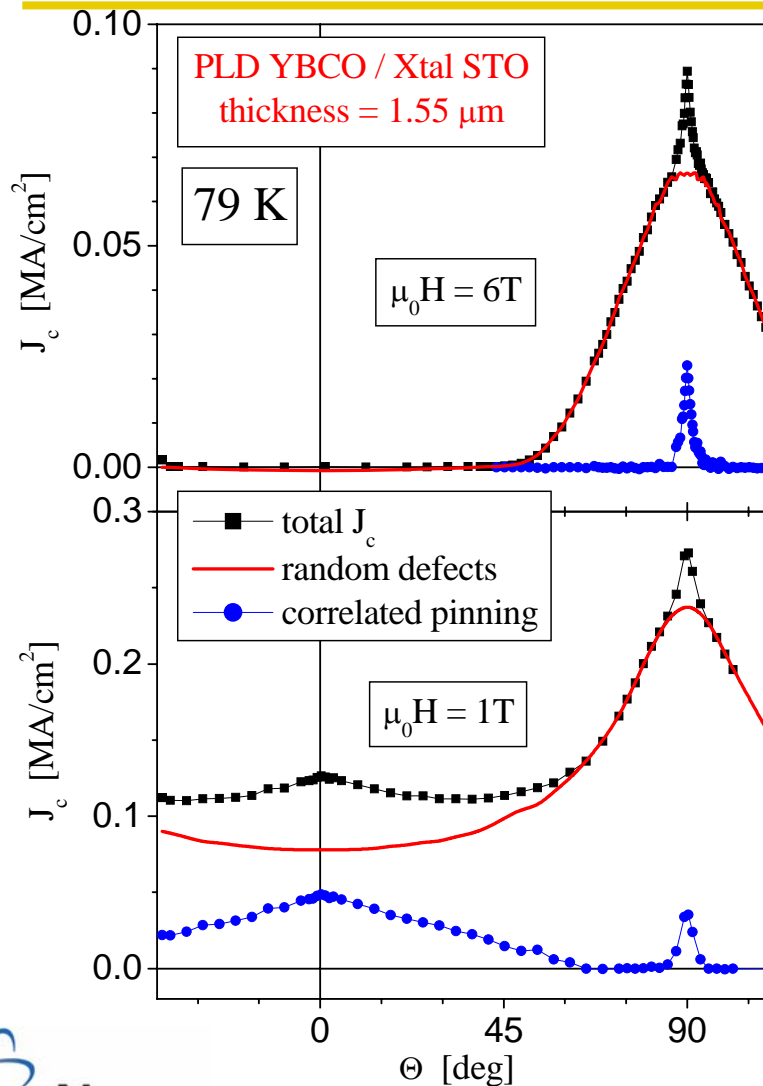


$J_c = 0 \Rightarrow$ ohmic response (resistance)

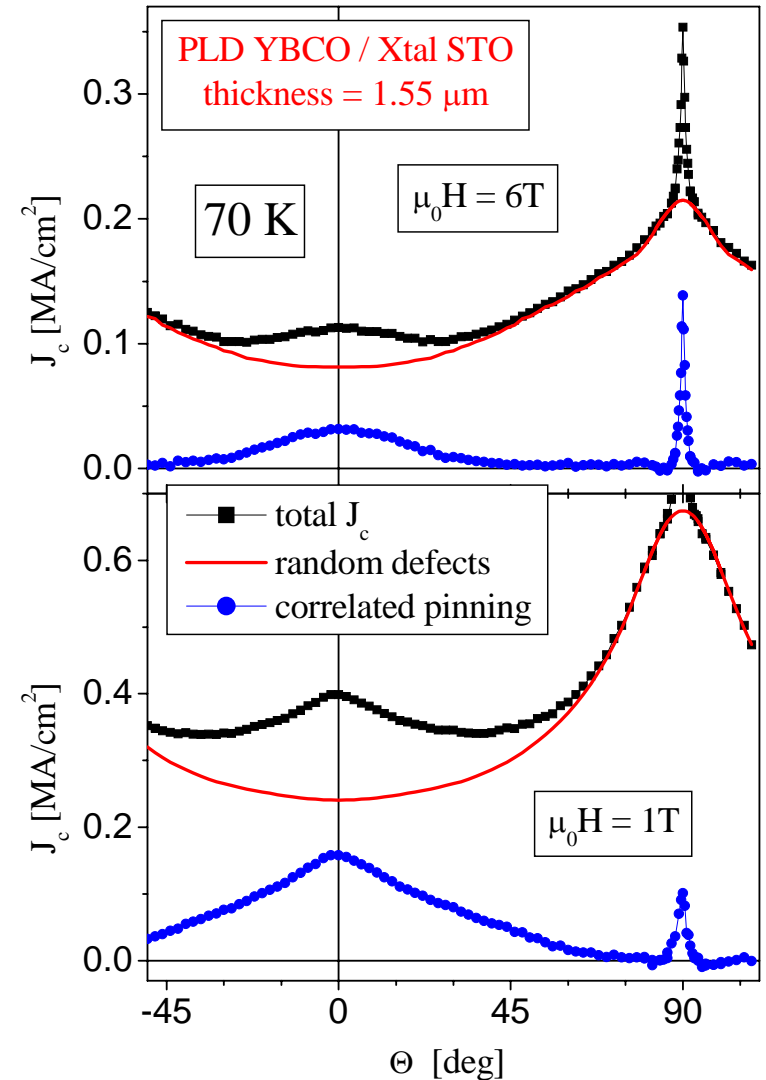
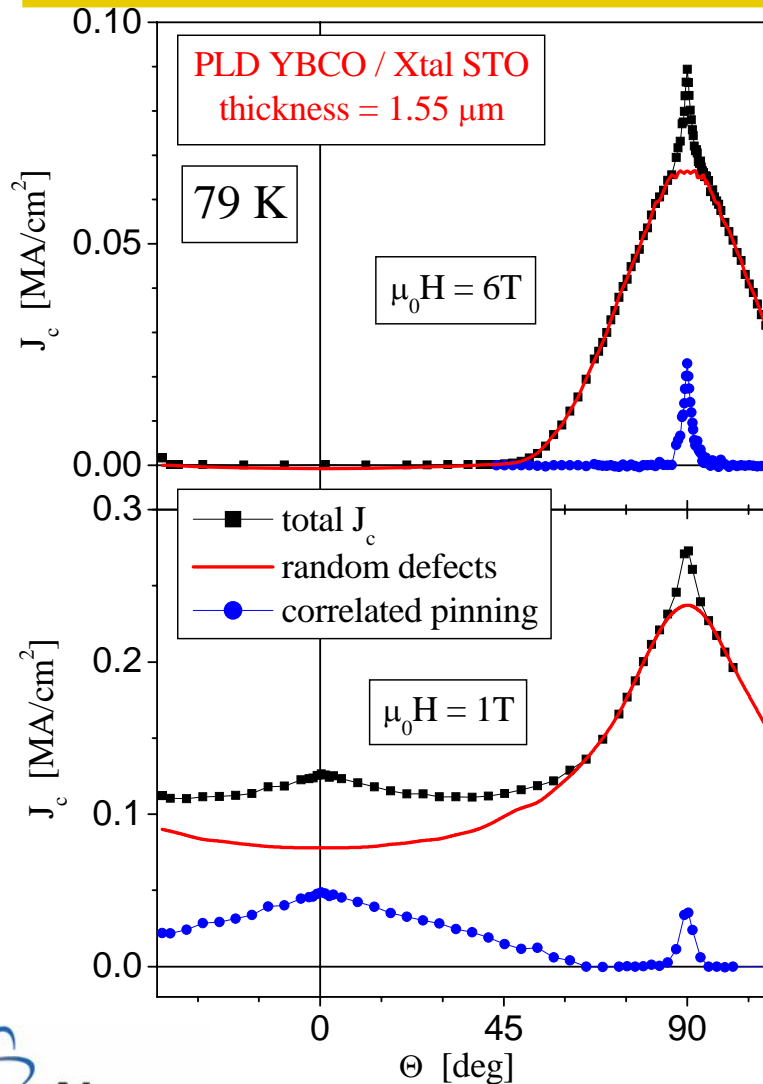
Our anisotropic scaling method also works at 79 K (temperature independent $\gamma = 5$)



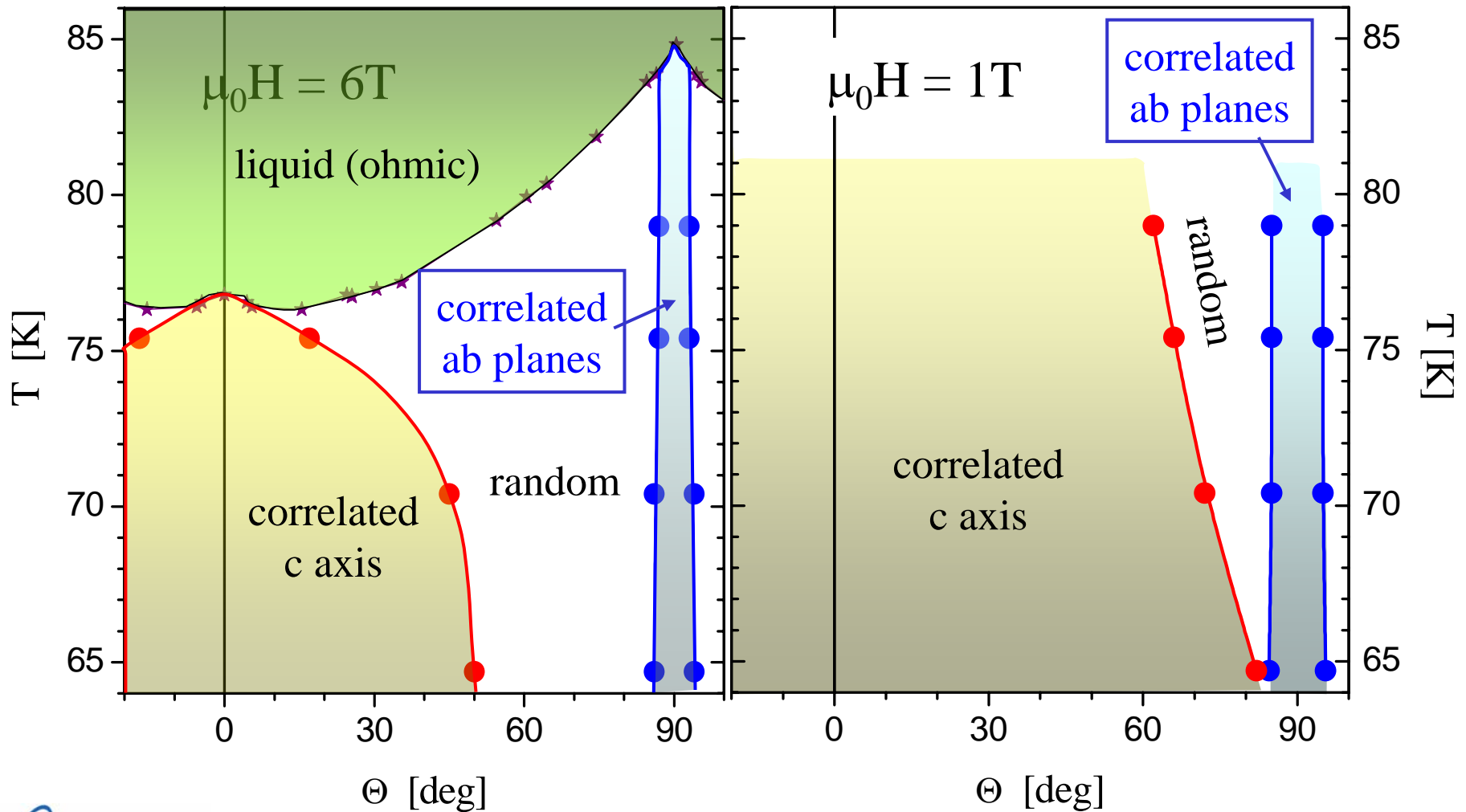
Separation of the uncorrelated and correlated disorder contributions to J_c



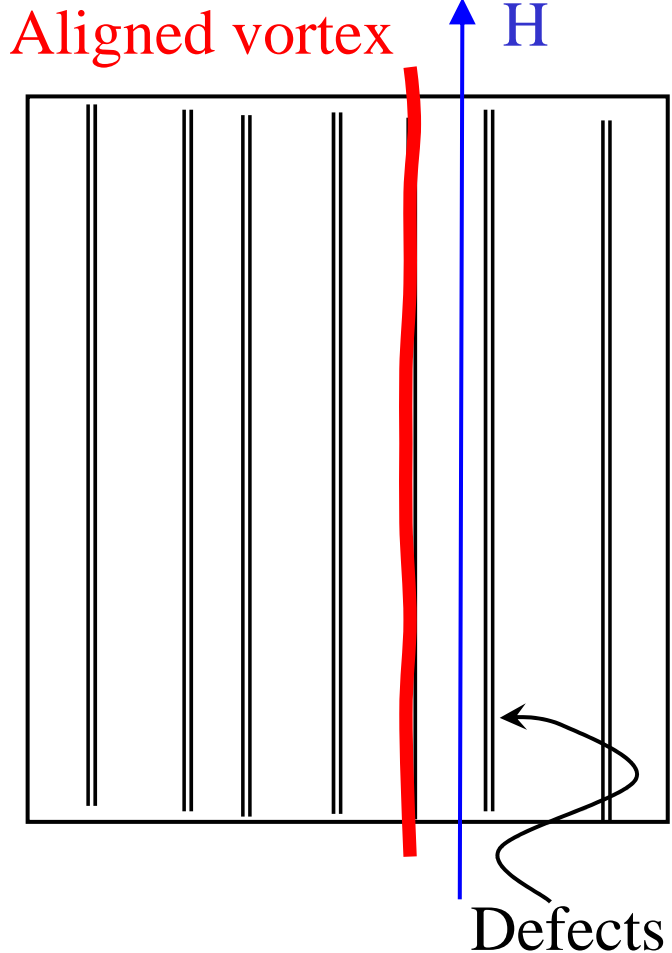
The importance of correlated disorder increases as T decreases



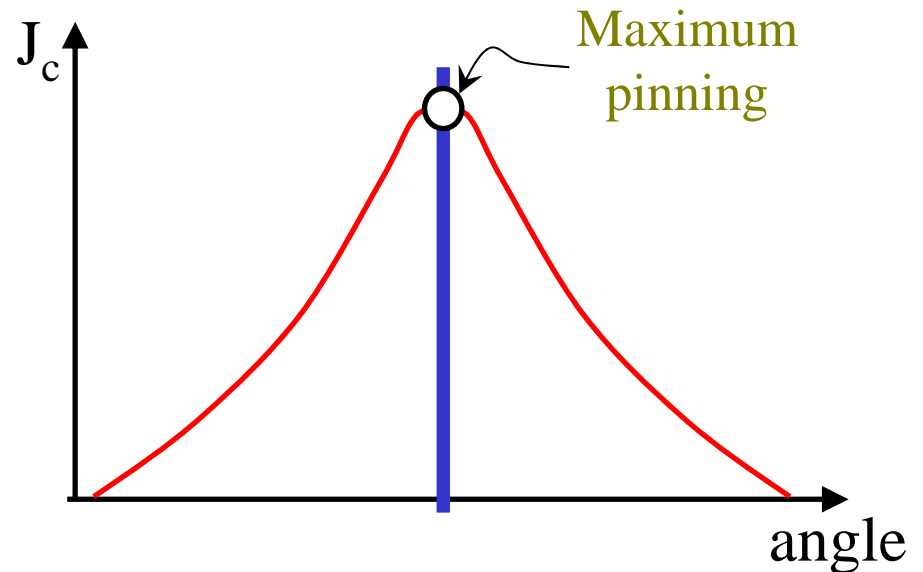
Phase diagram of the pinning regimes in PLD films



Directional pinning by correlated disorder



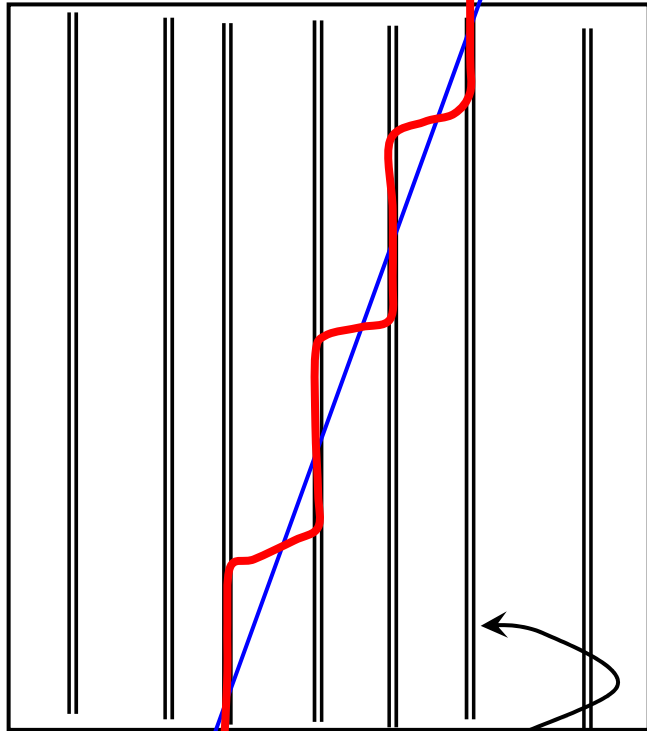
- ✓ Extended parallel defects
 - linear (dislocations, columnar defects)
 - planar (twin boundaries)
- ✓ $J_c \propto$ length of vortex that is pinned



Directional pinning by correlated disorder

“Staircase vortex”

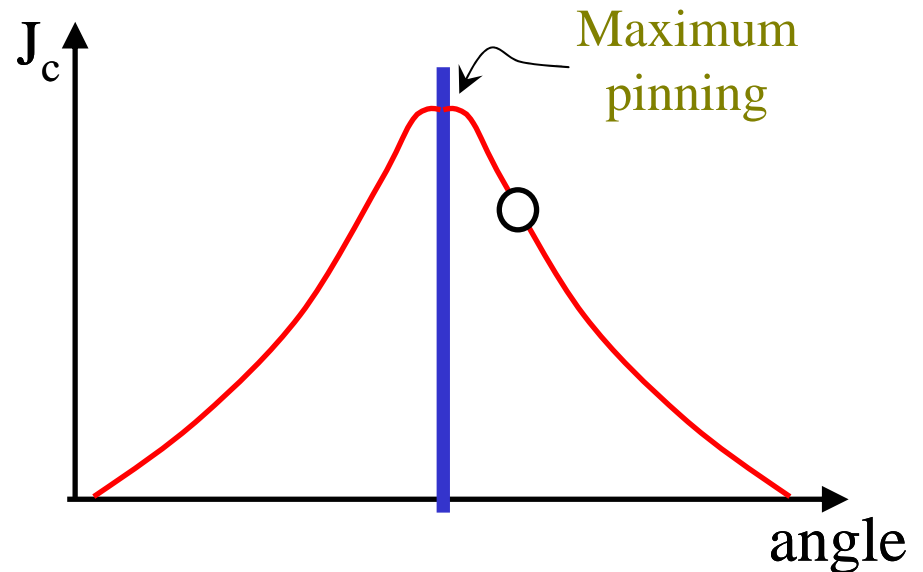
H



Defects

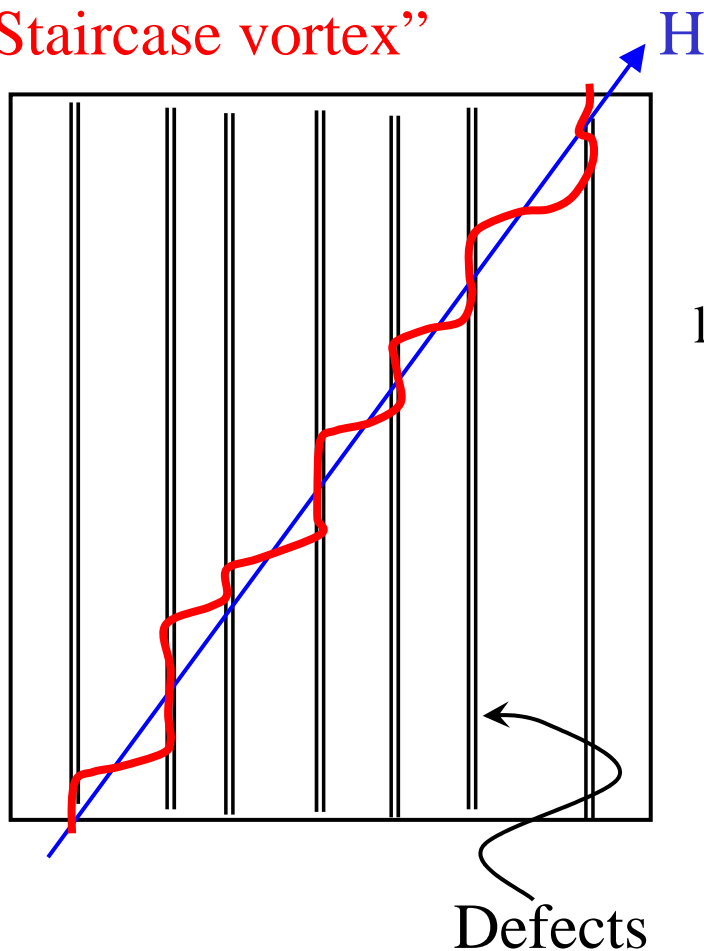
- ✓ Extended parallel defects
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larger angle \Rightarrow shorter pinned segments \Rightarrow lower J_c



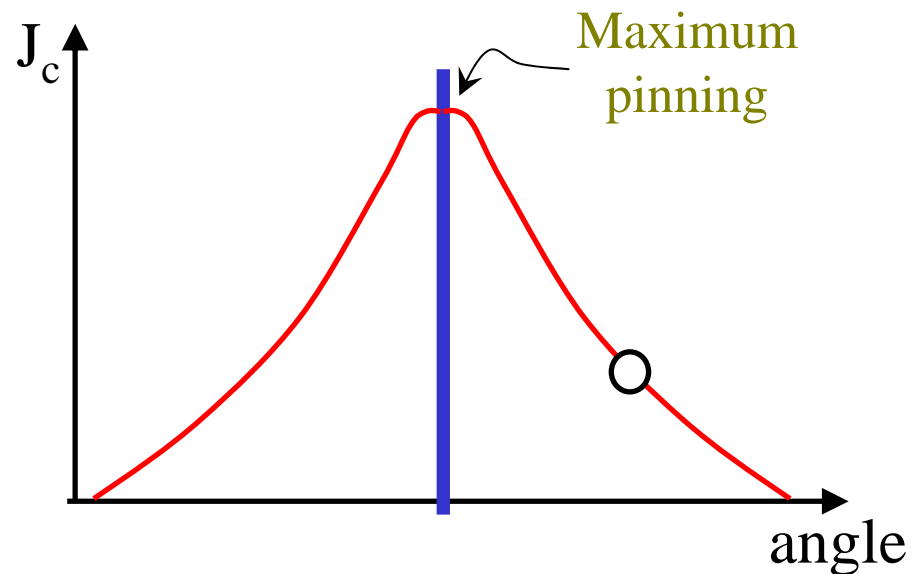
Directional pinning by correlated disorder

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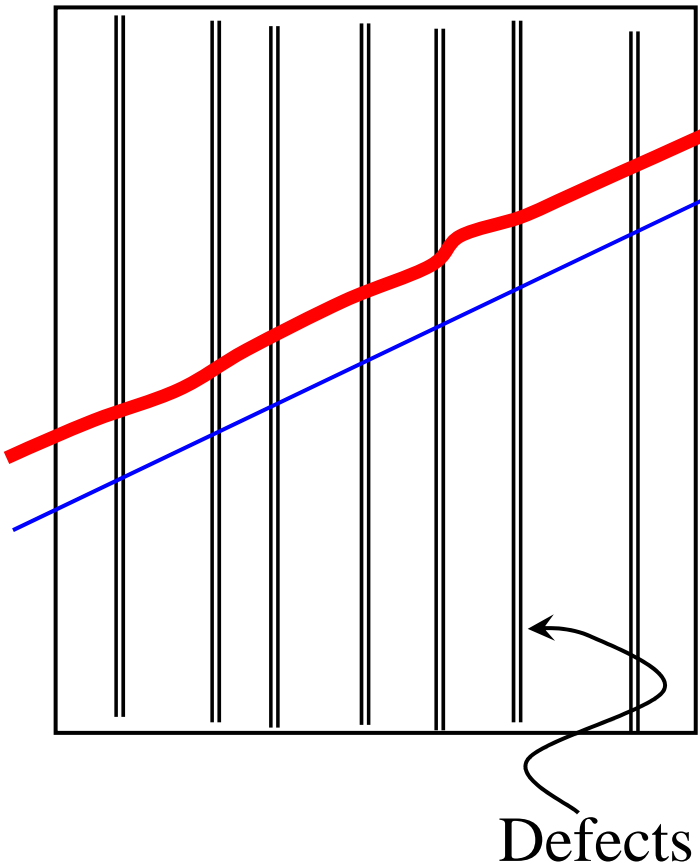
- ✓ Extended parallel defects
 - linear (dislocations, columnar defects)
 - planar (twin boundaries)
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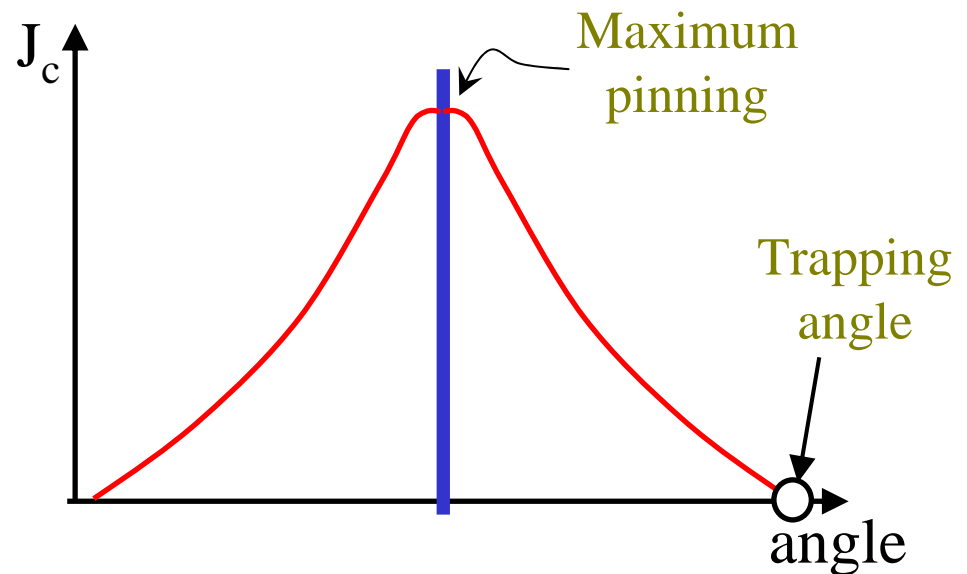
Directional pinning by correlated disorder

Unpinned vortex



- ✓ Extended parallel defects
 - linear (dislocations, columnar defects)
 - planar (twin boundaries)
- ✓ $J_c \propto$ length of vortex that is pinned

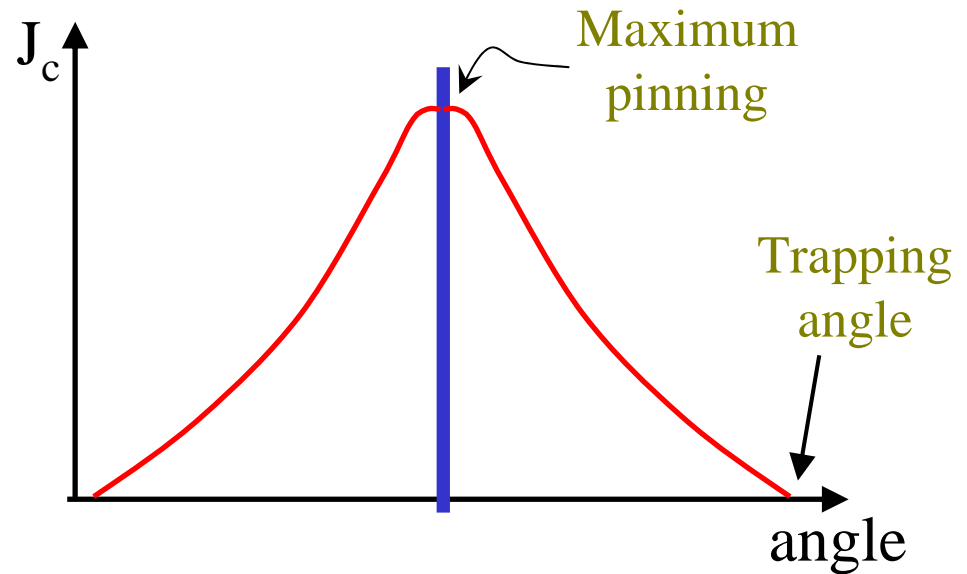
larger angle \Rightarrow shorter pinned segments \Rightarrow lower J_c



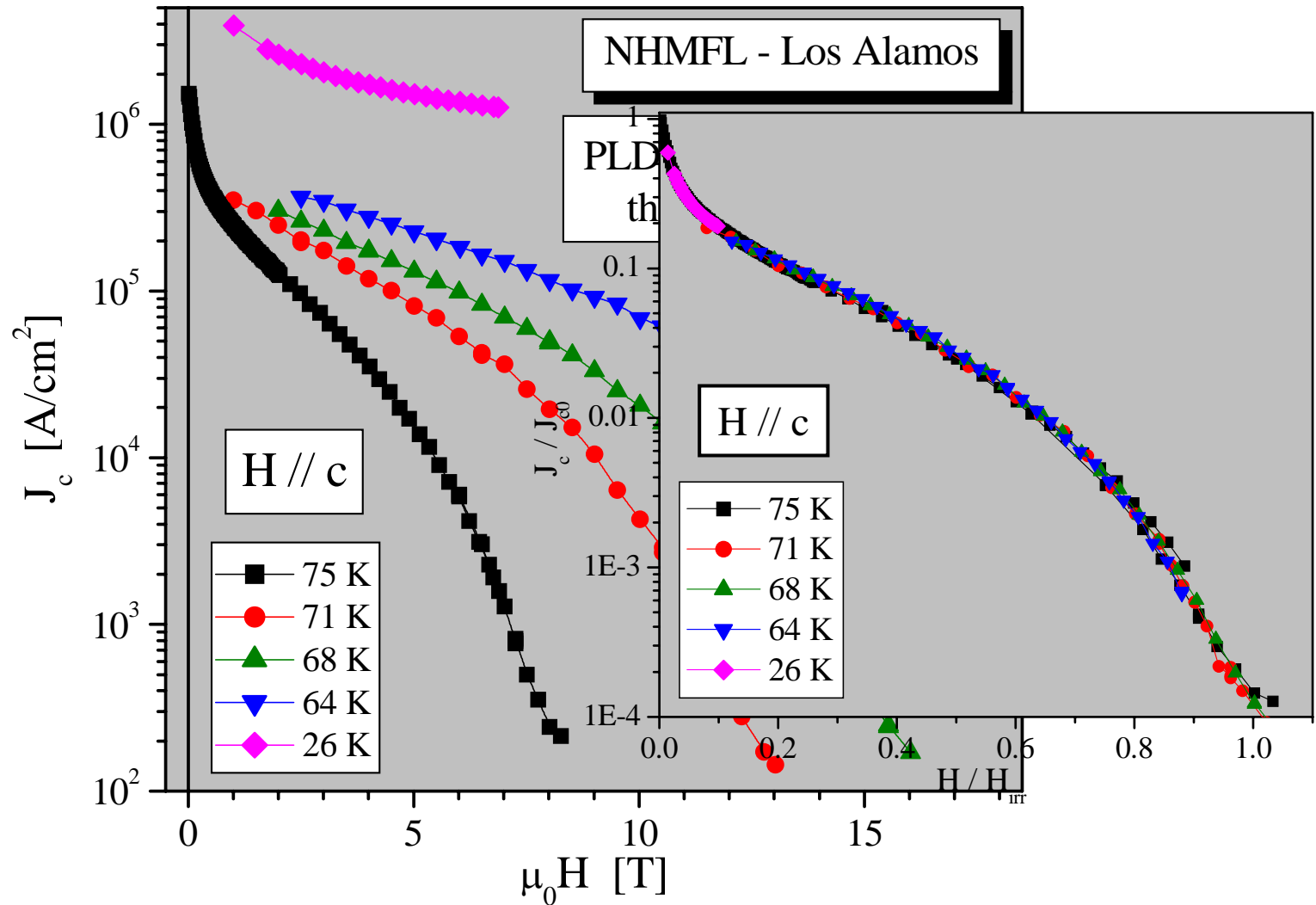
Both the height and width of the correlated disorder peaks are proportional to the pinning energy, so...

...they both increase with

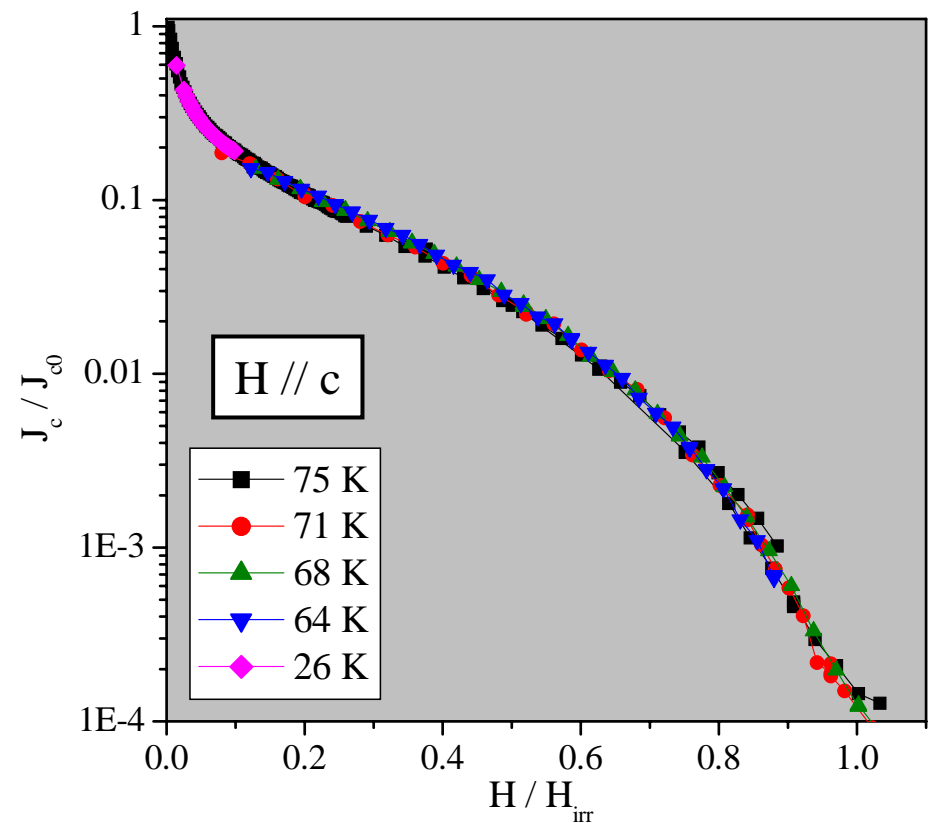
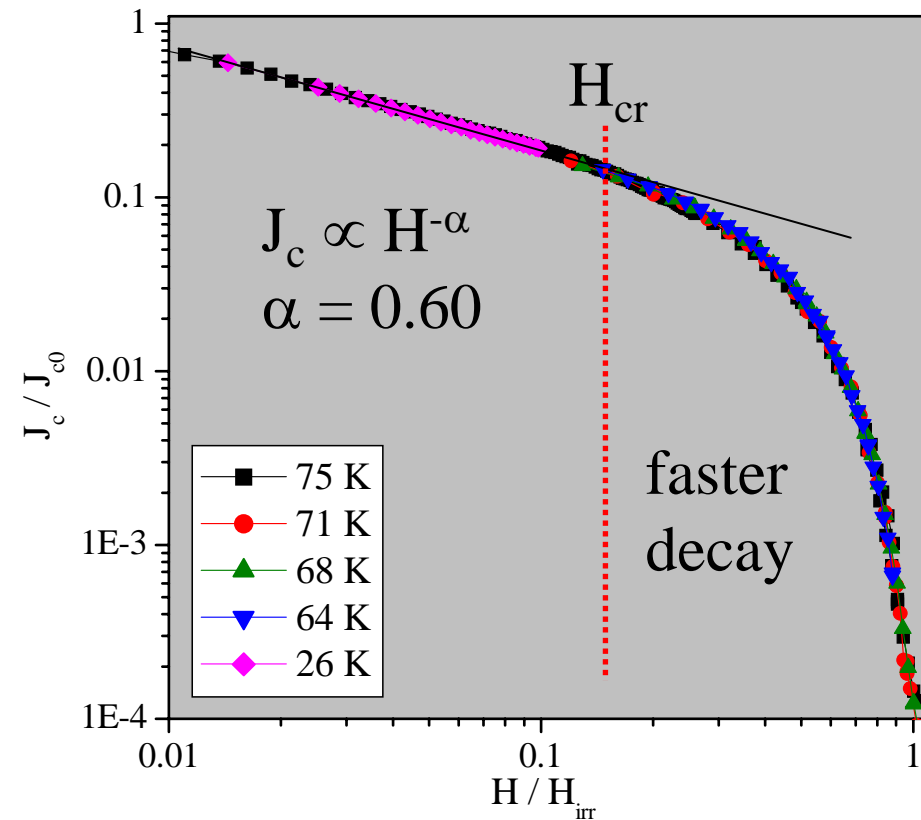
- decreasing temperature
- increasing density and/or strength of correlated defects



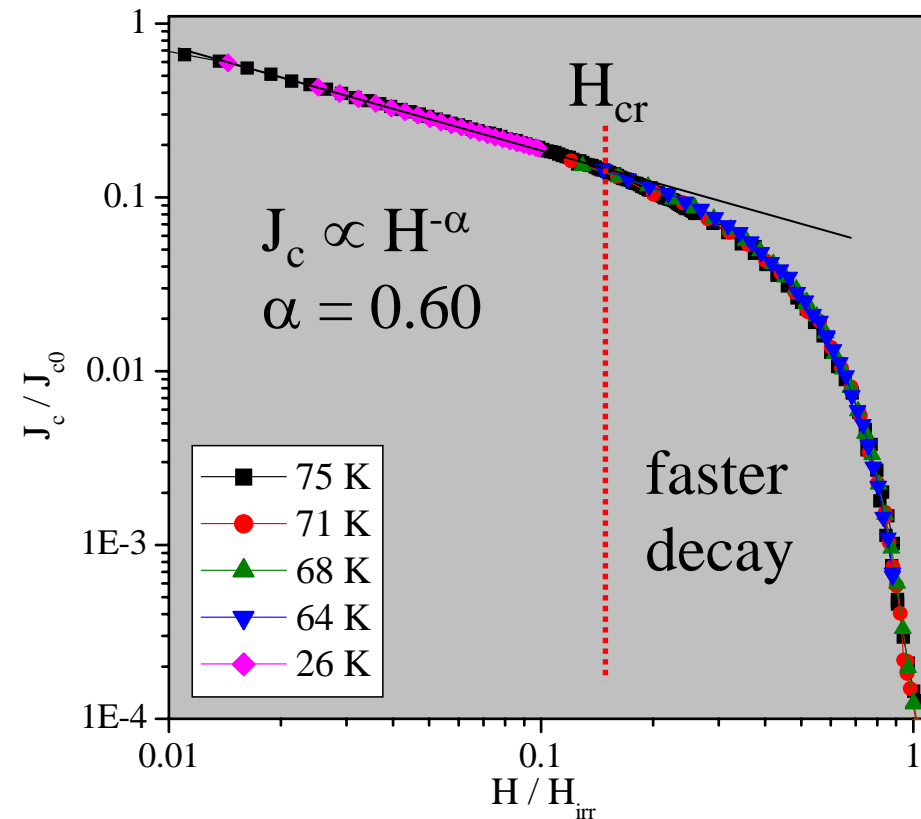
$J_c(H//c, T)$ can be scaled: possible to predict J_c value
 $H//c$: H_{irr} and J_c at high H grow strongly with decreasing T
 at given H, T



Different pinning mechanisms at low and high fields



Different pinning mechanisms at low and high fields



- α is temperature independent
 H_{cr} increases as T decreases
 $H_{cr}(T) \sim 0.15 * H_{irr}(T)$
- **$J_c \propto H^{-\alpha}$ is the technologically relevant regime**
- α is architecture-dependent and repetitive \Rightarrow useful characterization parameter
- smaller $\alpha \Rightarrow$ better field dependence

Extrapolation of H_{irr} and H_{cr} to low T

Below $T \sim 40$ K,
for $H // c$
we should only care
about the
 $J_c \propto H^{-\alpha}$ regime

